10/030907
JC13 Rec'd PCT/PTO 14 JAN 2002

METHOD AND DEVICES FOR MULTIPLEXING AND DE-MULTIPLEXING MULTIPLE WAVELENGTHS

FIELD OF THE INVENTION

The present invention relates to a device and system for separating or combining a plurality of wavelengths in a wavelength division multiplexed fiber optic system.

BACKGROUND OF THE INVENTION

The growth of communication systems using optical signals is currently growing at an unprecedented rate and is quickly replacing more conventional electronic means of communication. A major advantage of optical communication over electronic modes transmission is the immunity of the former to electromagnetic interference. The need for high speed transmission of more Information along optical waveguides such as optical communication fibers requires more efficient use of the available bandwidth.

A very powerful method of transmitting large amounts of information presently employed is wavelength division multiplexing (WDM). In this method several data streams are transmitted as an aggregate stream (multiplexed) along the optical waveguide. Each of the data channels transmits its information at its unique allotted wavelength. After the information carrying the optical signals at the different wavelengths traverses the fiber a predetermined distance, it passes through an optical de-multiplexer where the individual wavelengths are separated. The most common technique for constructing such devices is to use a series of band pass filters specially staggered to separate or combine the channels so as to incur minimum loss of the optical energy at each wavelength.

One cost effective approach for making these band pass filters is to use multilayer thin film technology. Thin film filters can be designed and subsequently packaged such that light of desired wavelength passes through and all others are reflected. For practical fiber optics applications, these types of filters are typically packaged with lenses so that light from an input fiber can be brought to the filter and the corresponding transmission and reflection can subsequently be collected with two output fibers. Since thin film filters are made on large glass substrates, this approach lends itself to low cost mass production.

However, as the channel spacing decreases from 200GHz to 100GHz and beyond, it becomes increasingly more difficult to manufacture the multilayer thin film filters necessary to separate or combine the tightly spaced channels.

Thin film filters offer the most economical approach to multiplexing and de-multiplexing optical signals that are separated by 200 GHz (1.6 nm) or more. However, as the need for greater bandwidth persists, system designers are looking to use tighter channel spacing in order to satisfy this burgeoning requirement in bandwidth. In fact, systems with channel spacing of 100 GHz (0.8 nm), and 50 GHz (0.4 nm) have been designed and are being deployed in limited numbers. Manufacturing of thin film filters for these more demanding applications is inherently difficult as yields tend to fall rapidly with tighter channel spacing.

United States Patent No. 6,040,932 issued to Duck et al. discloses a method for decomposing a composite signal into its odd and even components. Specifically, they have shown that by using a multiple of Fabry-Perot filters of different periodicity in conjunction with multiport circulators, it is possible to separate the original signal into its constituent odd and even members through a complex optical circuit. This is fundamentally different than what we show which relies on the use of a uniquely designed fiber grating employed in a simple optical circuit to accomplish the same. Our approach, however, uses fewer components and is much simpler to construct.

United States Patent No. 5,652,814 issued to Pan et al. describes a flexible coupler filter combination which when used in a tree structure can also be used to decompose a composite optical signal. This approach is, however, mainly based on using long pass thin film filters and separating the initial signal into two parts of short wavelength and long wavelength consecutively until the light signal is completely decomposed into its constituent members, i.e., $\lambda 1$, $\lambda 2$, ..., λn. This approach does not, however, provide a means for splitting the input optical signal into its odd and even components. These components could further be decomposed, or composed if used as a combiner, using standard demultiplexers. In addition, the inventors approach is limited to using thin film filters which tend to exhibit a much shallower transition from stop to pass as is suggested in the patent. In other words, the utility of the invention will be limited to channels that are not too closely spaced to one another. Our approach on the other hand utilizes periodic fiber gratings, i.e., sampled gratings, chirped moire

gratings, which can provide excellent rejection properties even for very closely spaced channels.

United States Patent No. 5,825,520 issued to Huber is directed to optical demultiplexers with grating reflectors de-multiplexing the input signal. However, this method requires a set of three gratings and a four port circulator for every two channels. In addition, the inventors have failed to recognize the limitation of their invention in that it is strictly limited to using fiber gratings and does not provide any upgradeability. In our case, the odd/even channel separator can be used in conjunction with conventional thin film filter devices to yield a hybrid filtering device superior in both performance and cost.

It would be very advantageous to provide a method and device for separating an optical signal having closely spaced channels into at least its even and odd wavelength components.

SUMMARY OF THE INVENTION

The present invention relates to a method and devices for separating or combining multiple wavelengths in an optical system. The present invention may be used in a variety of ways to more readily fabricate multiplexers and de-multiplexers using both multilayer thin film or fiber Bragg grating filters or a combination thereof. The invention can also be used, in part, to fabricate an odd/even channel separator to facilitate the use of wider bandwidth filters in applications where narrow bandwidth filters are required.

In one aspect of the invention there is provided a device for multiplexing and de-multiplexing multiple wavelengths in optical signals, comprising:

a first waveguide and an optical branching means optically connected to said first waveguide, at least second and third waveguides optically coupled to said optical branching means; and

at least one odd/even select filter optically coupled to said optical branching means for splitting an optical signal launched into said first waveguide into its odd and even wavelength components with one of said odd and even wavelength components being transmitted along one of said at least second and third waveguides and the other of said odd and even wavelength components being transmitted through the other of said at least second and third waveguides.

In another aspect of the invention there is provided an optical filter device

for multiplexing and de-multiplexing an optical signal having multiple wavelengths, comprising:

a first waveguide and an optical branching means optically connected to said first waveguide, at least second and third waveguides optically coupled to said optical branching means; and

at least one odd/even select filter optically coupled to said optical branching means for either

i) splitting an optical signal launched into said first waveguide into its odd and even wavelength components with one of said odd and even wavelength components being transmitted along one of said at least second and third waveguides and the other of said odd and even wavelength components being transmitted through the other of said at least second and third waveguides; or

ii) combining optical signals launched into said second and third waveguides with said combined optical signals being transmitted along one of said first waveguide.

BRIEF DESCRIPTION OF THE DRAWINGS

The method and devices for multiplexing and de-multiplexing a plurality of wavelengths forming the present invention will now be described, by example only, reference being had to the accompanying drawings, in which:

Figure 1 is a block diagram illustrating the function of the odd/even channel select filter constructed in accordance with the present invention;

Figure 2a is a spectrum plot of a chirped Moire grating;

Figure 2b is a spectrum plot of a modified chirped Moire grating to flatten regions of varying index and create multiple band pass filters with in the overall stop band of the filter;

Figure 3 is a block diagram of an optical circuit which includes a circulator as the optical branching device;

Figure 4 is a block diagram of an optical circuit constructed in accordance with the present invention using a pair of couplers in a Mach-Zehnder interferometer arrangement in order to separate the odd and even channels without using a circulator;

Figure 5a is a block diagram of an alternative embodiment of an optical circuit which includes a coupler as the optical branching device;

Figure 5b is a block diagram of another alternative embodiment of an

optical circuit which includes a coupler as the optical branching device;

Figure 6 is a diagram of the filter assembly cascaded to allow for complete separation of part or all channels; and

Figure 7 shows the odd/even channel select filter in a generic form coupled to an array of thin film filters with reduced channel separation for full decomposition of all the input channels.

DETAILED DESCRIPTION OF THE INVENTION

Referring first to Figure 1, the present invention embodies the use of an odd/even channel select filter 10 together with a fiber optic branching device to reduce the overall channel density and allow the use of lower grade filters for multiplexing and de-multiplexing of optical signals. This approach can be used in a sequential manner to reduce or increase the channel density by using specially fabricated odd/even channel filters with varying bandwidth. In other words, the highest density optical signal is broken up into its odd and even components and they, in turn, are broken up to odd and even components until all channels have been separated. Alternatively, the approach may be used to reduce the channel density and then use one of many conventionally used approaches to further separate the channels.

The method and system for multiplexing or demultiplexing optical signals disclosed herein may be implemented using waveguides for example semiconductor waveguides or optical fibers through which optical signals to be processed propagate.

The method forming the present invention allows for separating closely spaced optical channels by dividing the input signal into two output signals. The two outputs form odd and even signal paths such that the resulting channel density of each of the two outputs is at most half as much as the original signal. The odd/even filter 10 according to the present invention comprises an odd/even select channel filter together with an optic branching device to form two outputs or output ports each of which is at most half as densely populated as the original signal.

The odd/even channel select filter may be a chirped Moire Bragg grating, a sampled grating, a chirped sampled grating, a co-located grating or a series of individual gratings spaced along the waveguide. These channel select filters may be produced in optical fibers or produced in a semiconductor waveguide

chip.

Specifically, a preferred odd/even channel select filter grating is a chirped Moire fiber Bragg grating whose index modulation has been selectively erased at specific locations. A chirped Moire grating consists of two superimposed linearly chirped Bragg gratings, see Figure 2a. Designing the filter appropriately creates a comb like structure with flat top band pass structures in the optical spectrum. Combining this filter with a fiber optic branching device such as a fiber optic circulator or coupler would allow separating the signals into odd and even as formed by the comb like filter. In other words, every other channel would go through such a filter while every other channel, offset by one channel, would be reflected. In this way the reflected and transmitted channels will form the odd and even parts respectively of the initial signal.

Figure 2b(i) shows the spectrum of a chirped Moire grating whose index modulation has been erased in the middle creating the opening or band pass as shown. Figure 2b(ii) and 2b(iii) show the flexibility of the design in obtaining a variety of different responses.

In one preferred embodiment of the invention a specially modified chirped Moire fiber grating is used as the odd/even channel select filter. Formation of a chirped Moire fiber grating creates a wide stop band in the transmission spectrum as prescribed by the characteristics of the fiber, its index of refraction, and the chirp pattern. Chirped Moire gratings have spike like features in their overall stop band. These features are repeated periodically which by design creates a simple and elegant fix on the wavelength grid. Washing out certain regions of the index modulation, or stated in another way, erasing the grating in specific locations, in the chirped grating pattern simply creates the desirable flat top openings in the spectrum.

Referring to Figure 3, a device for multiplexing or demultiplexing multiple wavelengths using the aforementioned chirped Moire grating is shown at 20. The optic branching device comprises a three-port circulator 22 comprises an input fiber branch 24 along which the light signal containing the wavelengths to be separated propagates, a fiber branch 26 containing a chirped Moire grating filter 28 as discussed above with the output of filter 28 containing the odd wavelengths, and an output branch 30 through which the even wavelengths reflected from grating 28 are output. The circulator 22 is an optical fiber based component while the odd/even select filter 28 and the waveguide branches 24,

26 and 30 may be produced using optical fibers or produced on a waveguide chip.

In some applications it may be preferred to use a directional coupler for separating the odd and even channels such as illustrated in Figures 5a and 5b. In one embodiment of this arrangement, shown generally at 60 in Figure 5a, a directional coupler 64 is used to initially divide the input signal which is output from an isolator 62. An odd/even channel select filter 68 is used to pass the odd wavelengths through arm 70 output 2 and at the same time reflect the even wavelengths back through arm 72 to output 1 (or vise verse where even wavelengths are transmitted through filter 68 and odd wavelengths are reflected back through arm 72. The purpose of isolator 62 is to stop the reflection generated from the filter from returning to the input. This is quite important since any unwanted reflections in the opposite direction may result in instabilities back at the transmitter which would ultimately reduce overall system performance.

Referring to Figure 5b, in an alternative embodiment of the device shown generally at 80 the second arm 76 of the coupler 64 can be used where each of the two output arms 70 and 76 of the coupler 64 are outfitted with single or multiple channel select filters 68 and 72 respectively offset in each arm to allow the passage of even channels through arm 70 and odd channels through the other arm 76. In this configuration the channel select filter 68 passes the odd wavelengths and blocks even wavelengths (or vise verse) and channel select filter 74 passes even wavelengths and blocks odd wavelengths (or vise versa). This approach has the benefit that the power in odd and even channels as a result of the separation remains relatively the same. However, device 80 requires two filters each placed in one arm of the filter as opposed to the arrangement shown in Figure 5a which requires only one. The devices in Figures 5a and 5b may be fabricated into a chip containing the waveguides with the exception of the isolators 62 which are fiber based components.

Another embodiment of the device constructed according to the present invention is shown in Figure 4 and comprises a fiber optic Mach-Zehnder interferometer 40. Interferometer 40 includes two couplers 42 and 44 with the fiber 46 carrying the input light signal connected to coupler 42. The interferometer includes two arms 48 and 50 each containing two identically fabricated filters 52 and 54 respectively to separate the odd and even channels. The couplers 42 and 44 are used to combine the portions of the light that

interfere with each other as a result of the interferometer arrangement which allows the constructive and destructive parts of the interference to be separated with minimal loss to the optical energy. The odd wavelengths are output through fiber 56 connected to coupler 44 and the even wavelengths are output through fiber 58 connected to coupler 42.

Figure 6 shows an example of using the odd/even channel select filters by using any of the arrangements described hereinafter to separate all the wavelengths of an incoming signal. In these embodiments shown in Figure 6 the box-like elements represent odd/even filters used for the separation of the odd and even channels. The filter device in Figure 6 is used to demultiplex (or multiplex if used in reverse) an optical signal having n wavelengths. The wavelength filter device includes in total n-1 of the three port odd/even filter devices optically coupled in a cascaded series in which the two outputs of each odd/even filter forms an input port for two subsequent filter devices in the cascaded filter series. The individual wavelengths $\lambda 1$, $\lambda 2$, ..., λn are each output from the outputs on the last odd/even filters in the cascaded array or series. Each of the odd/even filter devices in the cascaded series in Figure 6 may be constructed as described with respect to Figures 3, 4, 5a or 5b.

Figure 7 shows the odd/even channel select filter in a generic form coupled to an array of thin film wavelength filters with reduced channel separation for full decomposition of all the input channels. This design has the advantage of using the fiber grating based odd/even channel select filter for reducing the channel density, while using the excellent properties of the thin film filter for final separation. United States Patent Nos. 6,067,178 and 5, 652,814, which are incorporated herein by reference, disclose how to demultiplex optical signals using thin film filters in the embodiment in Figure 7.

In one such arrangement, a widely chirped fiber grating with regions of constant index or a sampled fiber grating which consists of periodic regions of varying index and constant index can be used as the odd/even channel select filter. In the former, a widely chirped, spectrally broad, grating is holographically written into the core of an optical fiber which is subsequently exposed to dc UV radiation at the appropriate wavelength which creates regions of constant index in pre-selected locations. This effectively creates a chirped sampled grating whose spectrum will also have a comb-like structure. The main difference between a chirped sampled grating and a chirped Moire grating is the absence

of the spike like features in the spectrum for Moire gratings. These features can be used to provide an absolute fix in the wavelength spectrum. In other words, chirped Moire gratings whose index has been erased at pre-selected locations facilitate aligning the filter to the exact wavelength grid. On the other hand, sampled gratings are easier to manufacture so the final decision in respect of which filter to use will largely depend on the application. In addition, due to the nature of the grating formation, it may be beneficial to use the chirped Moire grating for obtaining better insertion loss.

In a variation of this embodiment, several co-located gratings are fabricated in the fiber which forms the comb like filter as described in the previous two embodiments. Co-located gratings are fiber gratings fabricated in the same physical location in the optical fiber. The advantage to making co-located gratings as opposed to individual gratings which are subsequently spliced together is the ability to package them in an athermal arrangement with significant space savings. An athermal grating is a packaged grating in a mechanical or thermal arrangement such that the characteristic thermal sensitivity of the grating's center wavelength is neutralized as described in US Patent No. 5,042,898 and incorporated herein by reference. This arrangement allows for a great deal of flexibility as any combination of filter shape and structure is possible through fabrication of these individual gratings which are co-located.

It will be understood that while the wavelength filter device disclosed herein has been illustrated for demultiplexing an optical signal with multiple wavelengths, it can just as easily be used as a multiplexer by using the outputs as inputs in which individual wavelengths are input into the outputs with a multiplexed signal being output at the first odd/even filter in Figure 6 or 7.

Thus, the foregoing description of the preferred embodiments of the invention has been presented to illustrate the principles of the invention and not to limit the invention to the particular embodiment illustrated. It is intended that the scope of the invention be defined by all of the embodiments encompassed within the following claims and their equivalents.